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COMPARATIVE OBSERVATIONS ON THE INDIRECT COLOR RANGE OF CHILDREN, ADULTS, AND ADULTS TRAINED IN COLOR.[1]

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The work already done in indirect color vision has been largely summed up in the original investigations of A. Kirschmann([1])[2], A. E. Fick([2]), C. Hess ([3]) and A. Fick.([4])

Kirschmann, with others, has shown that only a small part of the retinal surface is sensitive to the fundamental color impressions; that the retina is sensitive to impressions of blue much farther from the centre than to any other color impression, or giving the eccentric range of the different colors, he finds (beginning with the color having the greatest range and proceeding toward the centre) blue, yellow, orange, red, green, purple, violet.

He finds, further, that "The action of the peripheral retina varies greatly, in different directions, from the centre, and that the ranges of all colors extend farther in the nasal and

[1]This investigation was made in the psychological laboratory of the Leland Stanford, Jr., University, and the writer desires in this connection to thank Dr. Frank Angell and Prof. Earl Barnes for helpful suggestions and criticisms, and also Mr. J. C. Hammel, and others, for kind assistance in the laboratory.

[2]The small figures in parenthesis refer to the bibliography at the end of the article.

upper parts than in the lower and temporal parts of the retina." He also finds that the size of the colored objects has much to do with the extent of the range.

A. E. Fick finds, in going over an investigation of Charpentier,[1] that there is considerable mutual assistance of separate neighboring retinal spots in the perception of color and of light. He also finds that the centre retina is more sensitive to color and form impressions, while the eccentric retina, as we pass toward the periphery, is more sensitive to light and motion impressions, but much faster to some colors than to others; and that intensity has influence on the perception of light, color, form and number, but just how great is not determined.

The paper of Hess, published in 1889, is a very careful re-investigation of peripheral color vision, both spectral and pigment colors having been used, and its results partly support and partly supersede those of previous experimenters. He finds equal color ranges for red and green, and for blue and yellow, when these colors are of the hue of Hering's original colors *(Urfarben)*.

A. Fick's study, to which reference has been made above, concerns itself with the theory of color vision, and only touches indirectly upon the work which the writer has in hand.

The present investigation has been like that of Kirschmann, in being a study of the eccentric color range, but different, in being a comparative study of the eccentric color range of individuals differing in age, sex and previous color training.

After nearly two months of preliminary testing of both the perimeter and a flat surface apparatus (campimeter), it was concluded that the former possessed more advantages, with fewer disadvantages, and for this reason all the results recorded in this paper, excepting those on the upper and lower vertical meridians, were made on the perimeter. In the writer's opinion the errors arising from unequal illumination in different parts of the perimeter[2] are more than counterbalanced by the variation in angular magnitude in the case of the campimeter, especially when, as in the case of these experiments, the perimeter was illuminated equally from the sides, from behind and from a skylight; all windows being slightly to the rear of the observer. In fact, the results obtained on either apparatus were almost identical up to about 30° from the fixation point, but for greater distances the results given by the

[1] Arch. d'opht. Juli-August, 1886.
[2] Kirschmann([1]) S. 600.

campimeter were from 1° to 15° less than those given by the perimeter, varying with the angle. It is difficult to see how accurate results can be obtained on the campimeter, when the angular magnitude is greater than 30° until we know more definitely the effect of size and intensity on color vision.

The only meridians in which the illumination of the perimeter was thought to vary were the upper and lower vertical meridians, and as the color range in these is small, the campimeter was used for them.

The perimeter apparatus consisted of a darkened steel rod, made in the form of a half-circle, fastened to a black wall by a screw at its middle point. This rod could therefore be adjusted in any desired meridian, the screw on which the perimeter turned being the point on which the uncovered eye of the observer was fixed. The observer was seated in an adjustable chair which carried a head rest. In this latter his head was placed, with his eye on a level with, and just two feet away from the fixed point, or at the centre of the curve of the perimeter. The only difference between the campimeter and the perimeter above described was the substitution of a dark rule, eight feet long, for the semi-circular rod. This was fastened to the wall in the same way and graduated to inches and projected degrees.

The colors used consisted of Bradley & Co.'s colored cylinders (familiarly known as the Hailmann beads). The cylinders were 12 mm. long and 12 mm. in diameter, and were perforated with a small opening from end to end, by means of which they were easily fixed on the end of a darkened steel rod 2 mm. in diameter and 1 m. long, used for moving them along the perimeter. The colors were first brought into the field of vision from the periphery by the operator, and the exact place on the perimeter noted at which the color could be recognized by indirect vision. The color was then placed at the centre and gradually moved toward the periphery until it lost all color, all changes in color, and the places at which they occurred, being also noted. One eye of the observer was continually covered, while the other was kept constantly on the fixed point during the time the color was moving to or from the centre. The latter was permitted to turn about, however, during the time the experimenter was recording the past result or was adjusting a new color. Six colors were used—red, orange, yellow, green, blue and violet; more colors became confusing and were not named with accuracy. Purple and violet could not be accurately distinguished in indirect vision even by those most practiced in color discrimination, *e. g.*, teachers

of painting. Two persons who had had considerable experience as art teachers said they could not tell, as violet was being brought toward the centre, whether it was going to be violet or purple, and were only sure when it was within a few degrees of the centre. Possibly this may be accounted for by the fact that we have little or no experience in color discrimination in the peripheral parts of the retina, and color sensations there are not only different from those at the centre, but have also not become grouped or classified. The above is only true, however, of tints and shades of the same color or of neighboring color mixtures, for, as Kirschmann([1]) has observed, a spectral red, and a red carrying a little blue become noticeably different as they pass toward the periphery, the former changing to orange or yellow, the latter to blue. The same may be said of the other colors.

The colors used were supposed to be true imitations of the corresponding spectral colors, and were perhaps as exact imitations as it is possible for pigment colors to be. Fresh cylinders were used for each individual tested, so as to prevent all danger of change by use. Three double tests (*i. e.*, three tests with the color approaching the centre and three with color receding from the centre) were made with every color in every one of the eight meridians, and the average (range) of these tests taken as the one nearest correct.

The results obtained by the present investigation, in so far as they represent ground traversed before, agree with the results of Kirschmann([1]), Fick([2]) ([4]), Raehlmann ([5]), and others, in the following facts: (1) The ranges for the different colors were from 1° to 2° greater when the colors were moved from the centre toward the periphery than when they were moved from without toward the centre. (2) There are certain meridians in which the colors can be seen and recognized much further than in others. The upper nasal half of the retina is sensitive to colors farthest toward the periphery, while the under temporal part is sensitive to color over the least area. (3) The colors seem to arrange themselves in a certain definite order, according to the distance they can be seen in indirect vision. Beginning with the color having greatest range and proceeding toward the centre, we have first blue, then yellow, orange, red, green, violet. (4) The colors seem to fall into two rather noticeable groups—the blue-yellow group and the red-green group. Blue and yellow do not coincide in range but fall nearer together than in Kirschmann's investigation. The same is true of red and green. (5) As shown by Raehlmann([5]) all the colors used entered the field of color vision as either blue or yellow (*i. e.*, yellow or orange). Blue and yellow

give no sensation of color when seen beyond their range, unless different shades of gray may be called color. Green is generally seen first as yellow, and a few degrees nearer the centre is recognized as green. Red is generally seen first as yellow, then as orange, then as red, though often it is seen first as orange then as red. Orange is generally seen first as yellow, and violet is always seen first as blue.

The following facts may be inferred from other investigations, but I believe have not been stated: *e. g.*, blue is the most stable and permanent of all the colors. It is never mistaken for any other color, enters the sensitive color field as blue and remains a blue throughout the entire field. Green, although its range is very much less, comes next to blue in permanency; while it is generally seen outside of its range as yellow, yet there is quite sure to be found a certain definite place on every meridian within which the same observer is sure of the color. Yellow is perhaps the most variable: for example, in all the tests made on the same individual the range for blue never varied more than 3°, and the subject always felt sure when blue entered the field, whether he expected it or not. In green, the variation (with the same observer) was never beyond 4°, but he was not quite so sure as with blue. With yellow, on the contrary, the observer often varied from 1° to 10°, and never felt quite sure but that the yellow might prove to be orange, or red, or even green.

Another interesting fact is that violet is seen as blue a degree farther than the blue itself, but is not recognized as violet until within the range for green.

The variation between yellow and orange, as mentioned by Kirschmann[1] was not confirmed by the present investigation, as yellow showed a greater range than orange in every one of the eight meridians, and came as near to blue in one meridian as in another.

The purpose of the present investigation was, however, less to study the general subject of peripheral color vision than to answer the following questions:

Can children see colors in indirect vision as far as adults?

Does sex have anything to do with difference in the range?

What influence has color education on the range?

As this study was for the purpose of establishing the comparative range, great care was taken that all the conditions should remain as nearly constant as possible. All tests were made on uniformly clear days, between 2 and 4 P. M. As soon as the observer showed signs of fatigue or

[1] S. 609.

inattention, the work ceased and was resumed at another time. The writer made all the tests himself (assisted by Mr. J. C. Hammel, a fellow student in psychology), in order that there might be uniformity in the manner of presenting the colors, although the observer was always kept ignorant of the order or of the color approaching. The difficulties which occur here are, for the most part, similar to those which occur in all experimental work in psychology and need not be mentioned. There was one difficulty, however, which at times became very annoying, especially in the work with children, and as the writer has failed to find it mentioned by others, a little space will be devoted to it here.

The eye of the observer is supposed to remain fixed on a small surface at the centre (5 mm. in diameter in these tests) during the time the colors are approaching or receding, but as the color enters the field of vision the attention is diverted from the fixation point to the approaching color, and as the attention becomes diverted the eye often unconsciously follows it a little. The same is true when the colors are receding. In this way it often occurs that the eye has changed from 1° to 10°, or even 15° in children, without the observer being conscious of the fact. Some way of overcoming the errors which would result from this change of vision is necessary, and as the observer is not conscious of the fact he cannot be trusted to tell when his eye has changed. To avoid the above error it was found necessary for the operator to watch constantly the eye of the observer and not to record any results in which the eye wavered from the fixation point. Such a control would obviously be inapplicable to the dark room experiments that others have preferred.

Now for the answers to the questions. First: Can children see color in indirect vision as far as adults? The writer first obtained the color range of ten adults who were students in the university, but found later that he could not get so many children of any one age, and selected from the adults six whose color range seemed to vary least. He then obtained the color range of six thirteen-year-olds, and next the color range of six children who were seven-year-olds.

In Tables I, II, III and IV are presented the results of these investigations. The figures indicate the number of degrees from the centre point at which the colored objects could be correctly seen, and represent the external visual field. When referred to the retina the meridians must, of course, be reversed, the outer horizontal meridian would, on the retina, be the *i. e.*, nasal meridian, etc., etc. The average results are shown by diagrams in the plates at the end of the article. These diagrams

TABLE I.

SEVEN-YEAR-OLDS. CLASS I.

	MALES. A R	A L	B R	B L	C R	C L	FEMALES. D R	D L	E R	E L	F R	F L	Av. Range for every Meridian. R	Av. Range for every Meridian. L	Av. Range for Light and Shade R	Av. Range for Light and Shade L
Outer Horizontal,	38	40	42	42	42	43	42	42	38	40	40	40	40⅓	41	67	67
Outer Low. Obliq.,	34	34	32	37	38	33	37	37	35	35	33	35	35	35	62	62
Lower Vertical,	25	24	28	28	25	25	28	27	25	27	23	24	25⅔	26	40	40
Inner Low. Obliq.	25	25	26	24	25	25	28	27	25	25	25	24	25½	25	41	42
Inner Horizontal,	29	28	27	26	29	27	28	28	28	29	26	26	28	27⅓	42	42
Inner Up. Obliq.,	27	28	24	24	24	24	25	25	24	26	22	24	24⅓	25	42	43
Upper Vertical,	18	18	19	19	18	18	20	20	17	19	17	18	18	18½	34	34
Outer Up. Obliq.,	25	28	26	29	30	30	28	31	27	31	25	26	27	29	51	50
Average Range,	26⅓	28	28	28½	29	28	29½	29½	27½	29	26½	27	28	28	47½	47½
Sex Average,	28						28						47.4			

ADULTS. CLASS III.

	MALES. A R	A L	B R	B L	C R	C L	FEMALES. D R	D L	E R	E L	F R	F L	Av. Range for every Meridian. R	Av. Range for every Meridian. L	Av. Range for Light and Shade R	Av. Range for Light and Shade L
Outer Horizontal,	79	80	72	73	76	75	72	70	78	70	74	74	75	74	86	86½
Outer Low. Obliq.,	70	70	70	70	67	68	65	66	70	65	62	64	67	67	82	82
Lower Vertical,	45	45	42	44	40	38	42	42	40	38	36	38	41	41	50	49
Inner Low. Obliq.	36	38	40	40	36	36	38	38	38	35	36	38	37	37	50	50
Inner Horizontal,	38	42	42	40	42	40	37	38	40	36	39	39	40	39	54	55
Inner Up. Obliq.,	32	36	38	40	34	35	34	36	34	34	35	37	34	36	56	53½
Upper Vertical,	35	35	33	33	32	34	35	34	35	34	32	33	34	34	47	47
Outer Up. Obliq.,	46	42	47	40	46	43	45	44	44	42	46	42	46	42	64½	64
Average Range,	48–	48+	48	47+	47–	46	46	46	47	44	45	46	47–	46+	61	61
Sex Average,	47.4						45.7									

THIRTEEN-YEAR-OLDS. CLASS II.

	MALES. A R	A L	B R	B L	FEMALES. C R	C L	D R	D L	E R	E L	F R	F L	Av. Range for every Meridian. R	Av. Range for every Meridian. L	Av. Range for Light and Shade. R	Av. Range for Light and Shade. L
Outer Horizontal,	53	52	55	56	50	53	57	60	52	57	55	57	54	56	80½	81
Outer Low. Obliq.	47	47	48	50	47	53	51	50	52	57	50	48	49	51	77½	77
Lower Vertical,	29	30	30	31	32	32	33	35	29	29	27	32	30	31½	48	48
Inner Low. Obliq.	31	31	29	29	34	31	28	30	28	27	30	30	30	29	46	46
Inner Horizontal,	30	26	32	29	28	28	33	28	28	28	34	33	31	29	49½	49½
Inner Up. Obliq.,	27	22	27	25	28	25	25	25	26	22	30	24	27	24	49	49½
Upper Vertical,	21	22	22	23	23	25	25	25	24	24	26	24	23½	24	42	41½
Outer Up. Obliq.,	30	31	32	34	33	34	31	35	37	35	32	35	32	34	58	59
Average Range,	33½	33–	34+	35–	34+	35	35	36	34½	35	35½	35+	34½	35	56.3	56.4
Sex Average,	34–				35											

ADULTS TRAINED IN COLOR. CLASS IV.

	MALES. A R	A L	B R	B L	FEMALES. C R	C L	D R	D L	E R	E L	F R	F L	Av. Range for every Meridian. R	Av. Range for every Meridian. L	Av. Range for Light and Shade. R	Av. Range for Light and Shade. L
Outer Horizontal,	78	83	75	75	82	82	75	77	73	75	68	69	75	77	86	85
Outer Low. Obliq.	72	74	64	66	76	72	65	64	65	67	65	60	68	66½	80	81
Lower Vertical,	40	41	42	40	42	43	37	37	42	43	43	43	41	41	50	51
Inner Low. Obliq.	35	33	38	36	37	36	38	37	41	40	35	35	37	36	50	50
Inner Horizontal,	42	48	43	43	38	38	37	41	41	42	36	37	40	41	56⅓	55⅓
Inner Up. Obliq.,	35	39	42	38	37	37	36	35	44	41	36	36	38	38	57	54+
Upper Vertical,	38	34	30	30	32	31	29	29	31	32	34	34	32½	32½	47	47
Outer Up. Obliq.,	42	47	37	42	41	42	42	38	40	42	38	45	45	42½	61	62
Average Range,	48	50	46	46	48	48	45	45	47½	48	44	45	47	47	61	60.6
Sex Average,	47.5				46.2											

The External Visual Field for Blue.

The above represents the average results of three double tests of each individual through all the meridians as indicated. On this chart, in column eight, is also represented the average range for light and shade of each class. The letters, A, B, C, D, E, F, represent the different individuals of each class. R, right eye; L, left eye.

TABLE II.

Seven-Year-Olds. Class I.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	35	37	40	40	38	38	30	32	33	33	33	30	35	35
Outer Lower Oblique,	32	26	35	38	33	32	29	26	33	30	28	28	31	30
Lower Vertical,	21	20	27	27	23	20	25	25	20	21	20	20	23	22
Inner Lower Oblique,	24	21	22	22	24	22	23	24	20	25	24	19	23	22
Inner Horizontal,	28	29	25	22	26	22	20	21	24	27	24	24	24½	24
Inner Upper Oblique,	25	25	19	21	18	19	20	18	19	21	20	16	20	20
Upper Vertical	14	14	18	18	16	16	16	16	16	18	15	15	16	16
Outer Upper Oblique,	23	25	24	27	19	20	17	27	25	21	20	19	21	23
Average Range,	25+	25–	26	27	25	24	23	24	24	25	23	21	24	24
Sex Average,	25						23							

Adults. Class III.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	78	74	76	73	72	73	76	67	76	70	70	71	75	71
Outer Lower Oblique,	70	64	67	64	57	57	63	56	64	57	55	56	63	59
Lower Vertical,	42	42	38	43	35	34	45	42	42	42	34	36	39	39
Inner Lower Oblique,	30	36	40	40	37	38	32	34	38	32	36	34	35	36
Inner Horizontal,	42	42	40	37	40	38	37	37	40	35	36	38	39	38
Inner Upper Oblique,	33	36	40	40	37	34	31	35	34	31	30	30	34	34
Upper Vertical	37	37	34	34	32	33	35	35	38	30	33	34	35	34
Outer Upper Oblique,	46	45	47	45	47	46	46	45	43	45	44	43	45	45
Average Range,	47	47	48	47	45	44	46	44	47	43	42	43	46	44
Sex Average,	46.3						44							

Thirteen-Year-Olds. Class II.

	Males.				Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	55	52	57	55	45	54	55	59	54	54	57	57	54	55
Outer Lower Oblique,	44	46	45	48	45	54	53	50	53	49	50	48	48	49
Lower Vertical,	30	30	30	31	30	30	35	33	25	29	27	31	29	31
Inner Lower Oblique,	34	28	28	30	35	30	28	30	25	26	31	26	30	28
Inner Horizontal,	32	25	30	28	29	28	33	28	26	28	27	32	29	28
Inner Upper Oblique,	25	26	25	26	30	30	28	25	27	23	26	28	27	26
Upper Vertical,	20	22	18	23	22	20	26	25	21	20	23	26	22	23
Outer Upper Oblique,	28	28	27	30	30	31	33	35	40	35	32	33	32	32
Average Range,	33½	32	32	34	33	34	36	36	34	33	34	35	34	34
Sex Average,	33				34.5									

Adults Trained in Color. Class IV.

	Males.				Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	78	82	65	73	82	83	75	70	70	71	75	69	74	74½
Outer Lower Oblique,	55	66	47	46	70	70	58	52	60	64	65	64	59½	60½
Lower Vertical,	37	38	33	31	43	45	33	34	43	43	43	43	39	39
Inner Lower Oblique,	35	32	36	36	35	35	35	32	39	39	32	33	35	34½
Inner Horizontal,	37	44	38	43	34	38	35	36	40	40	34	36	36	39
Inner Upper Oblique,	35	38	38	38	35	37	32	33	41	42	34	33	36	37
Upper Vertical,	35	32	34	30	27	33	30	30	30	31	30	30	31	31
Outer Upper Oblique,	37	43	38	38	38	43	37	37	40	40	36	45	39	41
Average Range,	44	47	41	42	45½	48	42	40	46	47	44	45	44	44½
Sex Average,	43.4				44.5									

The External Visual Field for Yellow.

The above chart represents the average results of three double tests of each individual through all the meridians as indicated. The letters A, B, C, D, E, F, represent the different individuals of each class. R, right eye; L, left eye.

TABLE III.

Seven-Year-Olds. Class I.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	30	30	31	30	35	36	30	32	27	28	30	31	30	31
Out. Lower Oblique,	26	26	26	27	30	30	29	27	29	25	25	25	27	27
Lower Vertical,	19	20	20	20	17	17	21	21	18	19	19	19	19	19
In. Lower Oblique,	19	18	18	17	18	18	17	20	16	20	22	17	18	18
Inner Horizontal,	21	22	21	18	20	18	15	17	19	25	19	19	19	20
In. Upper Oblique,	20	19	16	16	16	20	17	16	17	20	18	16	17	18
Upper Vertical,	15	15	12	12	15	15	13	13	14	16	13	13	14	14
Out. Upper Oblique,	17	20	16	18	22	21	16	18	22	23	21	19	19	20
Average Range,	21	21	20	20	22	22	20	21	20	22	21	20	20	21
Sex Average,	20						20.5							

Adults. Class III.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	56	50	54	48	46	47	46	46	46	45	45	47	49	47
Out. Lower Oblique,	30	30	37	38	34	35	30	34	36	33	33	32	33	34
Lower Vertical,	20	20	23	20	23	25	25	26	20	22	22	23	22	23
In. Lower Oblique,	23	20	24	25	22	22	25	24	26	22	24	24	24	23
Inner Horizontal,	27	25	25	22	24	23	24	24	28	26	25	24	25	24
In. Upper Oblique,	22	25	28	27	25	23	22	22	27	22	22	23	24	25
Upper Vertical,	17	17	20	17	19	18	21	20	19	19	17	18	19	18
Out. Upper Oblique,	25	27	25	28	24	23	27	28	23	24	23	22	24	25
Average Range,	27	27	30	28	27	27	29	29	28	27	27	27	29	27
Sex Average,	27.8						27.2							

Thirteen-Year-Olds. Class II.

	Males.				Females.								Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	33	35	35	36	33	35	31	37	39	35	34	35	34	36
Out. Lower Oblique,	30	27	31	26	32	29	31	30	32	30	32	32	31	29
Lower Vertical,	20	20	20	20	19	18	19	19	16	20	17	21	18	20
In. Lower Oblique,	20	18	18	19	21	20	20	19	20	17	22	21	20	19
Inner Horizontal,	22	20	20	21	20	20	21	20	20	20	21	22	21	21
In. Upper Oblique,	19	21	20	19	21	20	19	17	20	17	20	19	20	19
Upper Vertical,	15	16	15	16	17	18	17	16	17	15	16	16	16	16
Out. Upper Oblique,	21	20	20	21	22	19	22	20	21	23	22	24	21	21
Average Range,	23	22	22	22	23	22	23	22	23	22	23	24	23	23
Sex Average,	22				22.7									

Adults Trained in Color. Class IV.

	Males.				Females.								Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	60	60	53	52	55	50	54	55	51	50	52	52	54+	53+
Out. Lower Oblique,	35	42	34	35	36	42	42	41	40	42	35	32	37	39
Lower Vertical,	25	22	26	26	25	28	24	23	33	32	31	30	27+	27–
In. Lower Oblique,	21	24	28	29	24	27	30	28	26	27	25	26	26–	27
Inner Horizontal,	27	30	32	32	25	30	30	31	27	33	28	27	28+	30½
In. Upper Oblique,	30	29	34	28	28	29	28	27	25	26	26	27	28½	28–
Upper Vertical,	26	20	21	20	22	23	21	21	20	20	23	22	22+	21
Out. Upper Oblique,	35	30	30	33	33	30	35	32	28	30	25	32	31	31+
Average Range,	32	32	32	32	31	32	33	32	31	32½	30½	31	31.7	32+
Sex Average,	32.2				31.7									

The External Visual Field for Red.

The above chart represents the average results of three double tests of each individual through all the meridians as indicated. The letters A, B, C, D, E, F, represent the different individuals of each class. R, right eye; L, left eye.

TABLE IV.

Seven-Year-Olds. Class I.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	23	27	25	27	25	25	24	28	21	23	20	20	23	25
Outer Lower Oblique,	23	24	23	24	22	19	23	25	21	19	21	21	22	22
Lower Vertical,	14	14	15	17	15	15	18	18	16	16	17	17	16	16
Inner Lower Oblique,	15	14	11	13	14	14	13	13	12	15	15	14	13	14
Inner Horizontal,	17	18	13	18	15	15	14	14	15	18	15	13	15	16
Inner Upper Oblique,	17	16	12	13	13	15	14	14	13	14	14	13	14	14
Upper Vertical,	11	11	11	12	12	12	11	11	12	13	11	13	11	12
Outer Upper Oblique,	15	16	14	15	17	17	14	15	18	17	17	14	16	16
Average Range,	17	17½	15½	17–	17	16½	16+	17	16	17	16	16–	16	17
Sex Average,	17–						16.5							

Adults. Class III.

	Males.						Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	43	42	44	40	37	37	44	42	40	43	42	43	42	41
Outer Lower Oblique,	30	30	36	35	33	30	31	31	32	30	32	31	32	31
Lower Vertical,	20	20	25	23	20	23	23	26	20	25	22	20	22	23
Inner Lower Oblique,	21	20	20	26	22	21	20	23	22	20	20	21	21	21
Inner Horizontal,	22	20	20	22	23	23	25	25	23	25	21	23	22	23
Inner Upper Oblique,	20	21	25	26	23	24	21	20	19	18	18	20	21	21
Upper Vertical,	19	18	18	19	17	16	21	20	18	20	18	19	18½	19
Outer Upper Oblique,	24	28	24	27	24	23	26	26	22	23	28	27	25	26
Average Range,	25	25	27	27	25	25	26	27	24½	25½	25	25½	24.4	26
Sex Average,	25.5						25.6							

Thirteen-Year-Olds. Class II.

	Males.				Females.						Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	32	31	35	32	33	33	33	32	38	35	27	31	33	32
Outer Lower Oblique,	27	27	28	28	28	25	31	28	30	28	25	29	28	28
Lower Vertical,	17	18	18	17	18	16	16	18	16	19	18	19	17	18
Inner Lower Oblique,	18	19	17	18	19	19	15	18	17	16	18	17	17	18
Inner Horizontal,	18	20	17	19	17	19	20	20	18	20	18	20	18	20
Inner Upper Oblique,	16	16	18	17	20	20	16	18	18	17	16	18	17	18
Upper Vertical,	14	15	14	15	17	14	17	17	16	15	14	14	15	15
Outer Upper Oblique,	19	18	17	17	20	16	17	17	19	20	17	16	18	17
Average Range,	20	21	21	21	23	20	21	21	22	21	19	21	20	21
Sex Average,	20.5				20.7									

Adults Trained in Color. Class IV.

	Males.				Females.								Av. Range for every Meridian.	
	A		B		C		D		E		F			
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Outer Horizontal,	37	40	31	32	43	38	33	34	40	40	30	32	36	36
Outer Lower Oblique,	26	32	26	27	35	28	28	30	33	33	30	27	30–	30–
Lower Vertical,	23	20	21	21	22	20	22	22	26	26	24	24	26–	24+
Inner Lower Oblique,	22	20	21	24	22	20	22	25	25	26	22	25	22	23
Inner Horizontal,	26	30	27	26	24	23	24	25	24	27	23	25	25	26
Inner Upper Oblique,	18	24	22	22	18	20	25	24	24	24	21	21	21	22½
Upper Vertical,	19	18	16	16	16	18	18	18	18	17	17	18	17	17½
Outer Upper Oblique,	22	25	26	22	21	21	23	27	22	22	21	22	22½	23
Average Range,	24	26	24	24	25	23½	24	25½	26½	27	23½	24	24½	25
Sex Average,	24.5				25									

The External Visual Field for Green.

The above chart represents the average results of three double tests of each individual through all the meridians as indicated. The letters A, B, C, D, E, F, represent the different individuals of each class. R, right eye; L, left eye.

also represent the external visual field, and must be reversed in order to represent the retinal color fields. In the tables and diagrams the results of only four colors (R. Y. G. B.) have been represented, as these seemed sufficient to illustrate the point and less confusing than more colors would have been.

On examining these tables one is impressed with the general similarity of the fields in persons of different ages. The general form of the visual field is, in all cases, somewhat elliptical, but more circular in youth. The extent of the visual field is evidently larger in the adults, and so uniformly is this the case that it seems safe to answer the first question, "Can children see colors in indirect vision as far as adults?" in the negative.

Representing the average range for the adult eye for the four colors as 100, the average for the thirteen-year-olds would be represented by seventy-seven, and the seven-year-olds by sixty-one. This, expressed in retinal surface, would be in the ratios of 100, fifty-nine, and thirty-seven respectively. The greatest difference in the range was found with the blue and the least with the red. The order, beginning with the color showing the greatest difference and ending with the one showing the least difference, is blue, yellow, green, red. There is, however, one exception to this order in case of the seven-year-olds, where yellow presents a greater difference than even blue. (See table.) Perhaps this can be accounted for in the hesitancy of the children to speak as soon as they received a sensation of yellow. The observer was always requested to speak as soon as he received any sensation of color whether it should prove to be true to the color approaching or not, but the children soon learned that what seemed to be yellow, might, on appreaching nearer, prove to be orange, red or green, and would often hesitate until they felt quite sure that it was yellow. The writer endeavored to overcome this cautiousness but was not entirely successful.

The question that now arises is: Why cannot children see color in indirect vision as far as adults? The discussion of this problem would require a paper in itself and must be deferred; however there are a number of points which present themselves. There are just as many degrees in the child's eye as in the adults, and so far as is definitely known, the retinal layer extends as far forward in the one as in the other. The difference in the convexity of the crystalline lens favors the child. We can hardly account for it through inattention, for the thirteen-year-olds seemed to be able to give as close attention to the approaching color as the adults, yet they

could recognize color only three-fourths as far. Again, the seven-year-olds could see objects 78% as far as adults, while they could see color only 61% as far. Although it is difficult to decide what the true cause is, yet the writer believes that the cause must be looked for in the order of the color development itself, whatever may be regarded as the true theory of color vision. Beginning with the visual color field, as seen by the adult, and passing backward toward and through the visual field of the child, we notice that the field not only decreases in extent but also becomes more circular. The same is true of the general visual field, *i. e.*, the visual field for light and shade, only the latter field decreases much less rapidly, or, in other words, shows a much greater proportional range in children than the color field. Now, should we continue still farther backward, and this law hold true, we should finally reach a point in the child's development where the eye ceased to be sensitive to color impressions; and from previous observations on young children, the writer would place this point not earlier than the fourth week of life, if as early as that. Perhaps no one will doubt the statement that the child becomes sensitive to light and shade much sooner than to color as color. A very young child may be attracted by a bright color, not on account of the color but on account of the light it contains. The above observations show that light and shade either develop faster in children than color, or else start sooner to develop, for while the range for light and shade of the seven-year-olds, as compared with adults, stands seventy-eight to 100, color, for the same individuals, stands as sixty-one to 100, linear measure. The writer very much questions whether his own children were able to perceive blue before they were eighteen months old, while they knew and seemed to enjoy red, orange and yellow very much earlier. If it be true that blue is the last of the colors to be perceived by the child, it becomes interesting to know why in after life blue has the greatest range of all the colors.

Judging from all the evidence at hand it seems probable that the child inherits from past generations an ever increasing color tendency, but nothing more, that he must come in contact with the real colors, or, in other words, the different color stimuli must play on the retina in order to develop this color tendency into a real mechanism for the discrimination of color, and that this mechanism begins to develop in earliest childhood, develops slowly and is finally completed in adult life. Further discussion of this point must be reserved for a future paper.

The second question was: Does sex have anything to do with difference in the range? There is a prevalent belief that woman has a better color eye than man, *i. e.*, greater inherent power of seeing and discriminating color, and that there are more color-blind men than women. The writer doubts, however, whether these beliefs are founded on facts. At least a carefully arranged and conducted experiment on 200 children (a number too small, perhaps, for accurate judgment) showed practically no sex differences in color vision. In the present experiment on visual range the data are entirely too limited to warrant any definite conclusions in the matter of sex, but the figures at least do not show that woman possesses any color superiority over man. In Tables I to IV, we find in Class III, designated adults, where there were three male and three female observers, that the average range for the males with blue was 47.4°, for the, females, 45.7°; the range of yellow, for males, 46.3°, for females 44°; the range of red, for males, 27.8°, for females, 27.2°; the range of green, for males, 25.5°, for females, 25.6°, or representing the average range of all colors for males at 100%, the average range for females would be 97%. Also in Class I (the seven-year-olds), where all the conditions were equally favorable to both sexes, we find again the males leading by 2%, or representing the average range of the boys for all colors as 100%, the average range for the girls would be represented by 98%. In Classes II and IV we find the conditions less favorable, for in each of these classes there were only two males and four females. Besides, in the class of thirteen-year-olds, where we should expect, if anywhere, to see a difference, the average age of the boys was nearly a year less than that of the girls, and this of itself may have been sufficient to account for the difference in the range in favor of the girls. Representing the average range of the boys as 100%, the average range of the girls would be 103%. In Class IV, where there were two men and four women, the average range favored the men by only 0.1%, or again representing the average range of the men as 100%, the average range of the women would be 99.9%.

These figures, so far as they show anything, show that man possesses not only equal power of recognizing the fundamental colors, but also equal retinal surface sensitive to color.

Let us now turn to the third and last question: What influence has color education on the extent of the range? To the answer of this question the writer brings the results of his observations on twelve different individuals, six of whom were selected from students of the university who had had

no special training in colors, and six others of equal age selected from the students and instructors of the Art Department who had had three or more years of special training in color.

In selecting the first class the author relied on his own judgment, but in selecting the second class he relied principally upon the judgment of Prof. Brown of the Art Department, who himself kindly submitted to the test, and endeavored to recommend only persons who showed special talent in color discrimination and in color harmony. The one class is indicated in the tables as "Adults, Class III," the other, as "Adults trained in color, Class IV."

Perhaps the best and only sure way to answer this question would be to select a number of individuals of the same age and of equal color range, giving to half of them three or four years of special color training, while the others were educated along other lines, without particular reference to color, and then take the color ranges again and compare. But in the absence of data gathered under these conditions, the present carefully made observations are of interest.

Table I shows that with blue the ranges for both the trained and the untrained were practically the same. With yellow, the range was greater for those untrained; while with red there was a decided difference in favor of the trained. The range for green was slightly greater in those untrained. Representing these in percentages and indicating the range of the untrained each time by 100%, we have the following results: The average range for blue in the untrained, 100%, in the trained, 100.2%; the average range for yellow in the untrained, 100%, in the trained, 97%; the average range for red in the untrained, 100%, for the trained, 115%; the average range for green in the untrained, 100%, in the trained, 97%. If the average range for all colors in the untrained were indicated by 100%, the average range for the trained would be 101.8%. This difference, although favoring those trained in color, falls within the individual variations of the same class, and is too small to be taken into account in tests of this kind. And judging both from the figures and the many impressions received during the time the tests were being made, the writer is forced to conclude that color education, as generally understood, has no influence on the color range. But is not this conclusion opposed to the one reached in answer to the first question? If correctly understood it is not. There are two kinds of color education, the direct and the indirect, the conscious and the unconscious, and it is on the indirect and unconscious sort of education, in which all share alike, that the widening of the color field depends.

That these incidental color experiences are necessary to the development of the range is shown by the general form of the color range itself. On the meridians which the nose and eyebrows shield from the color impressions, the retina is sensitive to color over only a few degrees as compared with the rest.

We mean something quite different, however, when we speak of direct color education. When an individual receives color instruction the colored objects are not brought to play on the periphery, but on a small spot at the centre of the retina, and here all color education or training, in the general acceptation of the term, takes place.

There is, therefore, no reason for thinking that those trained in direct color vision ought to see farther in indirect vision than the untrained.

Of other points of interest in this comparison of the trained and untrained may be mentioned the marked difference in the range for red in favor of the trained, of yellow in favor of the untrained, and the greater variety of shades seen by the trained, as well as the greater uncertainty in naming the true color. What color training really does, is to increase the number and variety of the color tones consciously recognized, but it does not increase the amount of retinal surface sensitive to color, and the greater the variety of color tones seen by an individual, the less accurate he becomes in naming the fundamental colors by indirect vision.

Another rather interesting fact was the not unusual occurrence of small color-blind surfaces in eyes otherwise apparently normal. These surfaces varied from 2° to 10° in breadth. Such a color-blind area can be seen in the Tables I to III, by referring under "Class IV" to the outer upper oblique meridian of the right eye of "F." In this case the color-blind area was so situated as to reduce the limit of vision on this meridian several degrees as compared with the other eye. The persistence and irregularity of these spots in some individuals was quite marked.

Again, in the examination of a person who was red-green color-blind, there were found small unequal areas in the excentric retina of both eyes (near the normal limit for red and green), where all the fundamental colors could be correctly distinguished.

It appears, then (to sum up), 1st, that children cannot see colors as far in indirect vision as adults, but as compared with adults they show a greater proportional range for black and white than for color.

2nd. Difference in sex seems to make no perceptable difference in the extent of the color range.

3d. Color training does not seem to increase the color range (except perhaps in the case of red), but makes itself felt in a greater variety of shades and tints to the colors as seen in indirect vision, and less accuracy in naming the fundamental colors by indirect vision.

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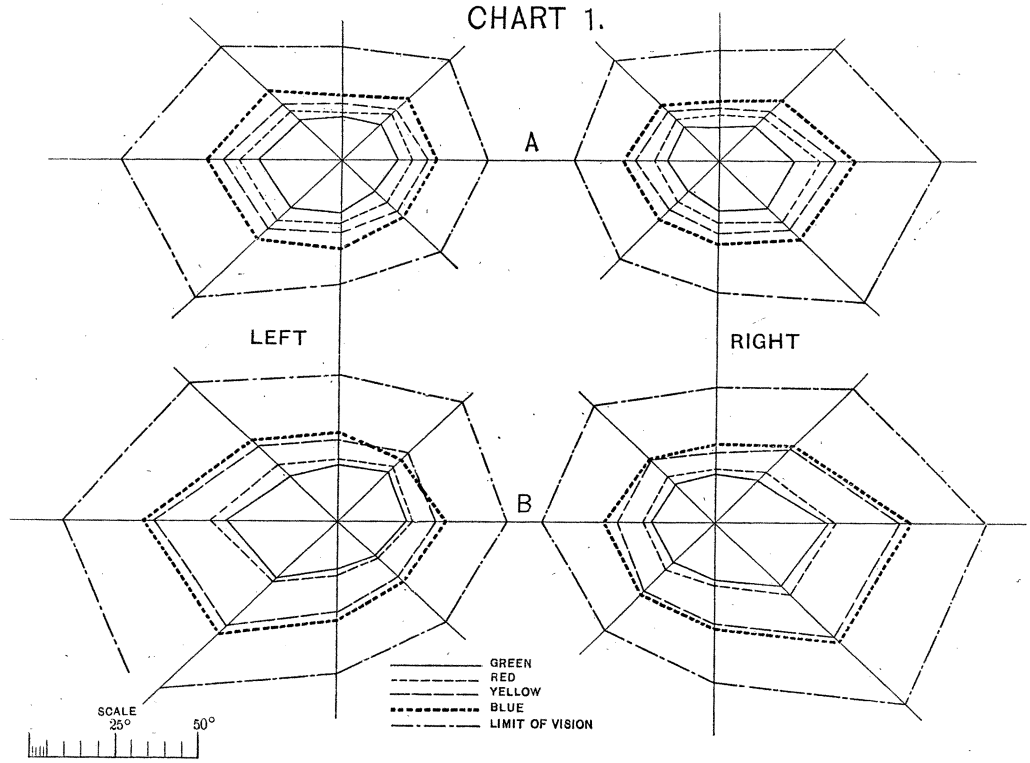

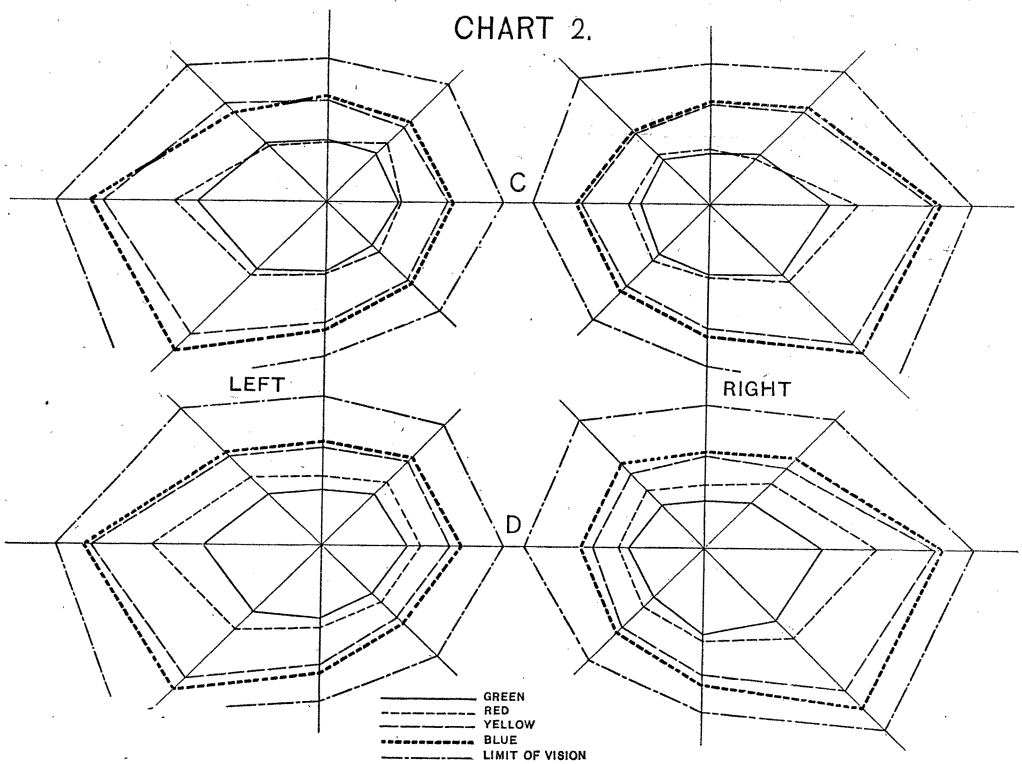

EXPLANATION OF CHARTS 1 AND 2.

CHART 1, A represents the average projected color field of the left and right eyes of six children seven years old. B represents the average projected color field of six children thirteen years old.

CHART 2, C represents the average projected color field of six adults. D represents the same field of six adults who had had three or more years special training in color. The line marked "limit of vision," is the average distance at which the class could see a white object of the same size as the colored objects used. By an unfortunate error in the reproduction of the original drawings Chart 2 is not shown on the same scale as Chart 1, but on a scale nearly one tenth smaller. For this reason the limits of vision in C and D seem smaller than in B, though in reality they are clearly larger.

The straight radiating lines are the meridians along which the colors were brought into the field of vision.